NASA Technical Memorandum 58242

NASA-TM-58242 19820013160

Preliminary Sonic Boom Correlation of Predicted and Measured Levels for STS-1 Entry

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NASA

National Aeronautics and Space Administration

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Houston, Texas

pages changed 8-3-83

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Replacement pages are attached for the following changed pages.

Page 13 - 4th column of table IV changed

Page 18 - caption for figure 3 added

Issue date: 4-7-82

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**Scientific and Technical
Information Office**

1982

N82-21034 #

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SUMMARY

A preliminary analysis correlating peaks from sonic boom pressure signatures recorded during the descent trajectory of the Orbiter Columbia, with wind tunnel signatures extrapolated from flight altitudes, has been made for Mach numbers ranging from 1.3 to 6. The flight pressure signatures were recorded by microphones positioned at ground level near the descent groundtrack along the California area, whereas the wind tunnel signatures were measured during a test of a 0.0041-scale model Orbiter. The range of overpressures recorded during Orbiter descent was from 33.5 N/m^2 at M=6 to 114.9 N/m^2 at M=2. The difference between flight-measured overpressures and those predicted from wind tunnel signatures, using preliminary actual trajectory data, ranged from 2.4 N/m^2 at M=6 to 33.5 N/m^2 at M=1.5. The flight signatures with the exception of M=6 exhibited a shape very similar to theoretical N-waves, while the M=6 signature has a rounded peak as opposed to a sharp peak. This difference in shape is not fully understood and will be the subject of future studies.

INTRODUCTION

No fully theoretical methods are available for calculating the sonic boom overpressures generated by blunt vehicles with detached shock wave maneuvering at high Mach numbers and high angles of attack. Therefore, sonic boom estimated for Space Shuttle Orbiter type vehicles must be based on one of the currently available semi-empirical techniques (refs. 1 and 2). With these techniques, near field pressure signatures measured in wind tunnels are extrapolated to the far field in a real atmosphere under actual flight condition. In order to extend the range of conditions for which these techniques are valid, measurements were conducted in the early 1970's using the Apollo 15 and 16 command modules as test vehicles. Results from both of these flights are reported in references 3 and 4, respectively, and agreement between predicted and flight results was good. This agreement provided some level of confidence on the ability of semi-empirical techniques to predict Orbiter sonic boom overpressure levels during descent. These predicted levels are presently baselined

as required by law in the Space Shuttle Program Environmental Impact Statement (ref. 5). This report presents results based on oscillograph traces of flight pressure signatures recorded during the descent of the Orbiter Columbia from microphones placed at ground level under or near its descent groundtrack along the California area from M=6 to M=1.2. These pressure levels are then compared with estimates based on the wind tunnel data of references 6 and 7 and preliminary postflight trajectory data using the extrapolation procedure of reference 1.

APPARATUS AND METHODS

Test Vehicle

A schematic of the STS-1 Orbiter Columbia (descent configuration) whose sonic boom levels were measured during entry is shown in figure 1. The Orbiter Columbia is a lifting vehicle capable of maneuvering and landing much like an airplane by using its control surfaces which are augmented by a reaction control system. As such, during its atmospheric flight, it is capable of flying at angles of attack as high as 40 degrees and rolling about the velocity vector to ± 70 degrees. Figure 2 is an actual photograph of the Orbiter Columbia in flight on its way to a landing at the Edwards Air Force Base (EAFB) dry lake bed in California, terminating the STS-1 mission. Columbia has an overall length of 32.7 meters and had a gross weight at entry interface (121 951.2 meters altitude) of 90 720 kg during the STS-1 mission.

Test Area and Arrangement

The general test areas associated with the entry of the Orbiter Columbia during the STS-1 mission are shown in figure 3. In order to define these test areas, a preflight STS-1 sonic boom analysis was performed. This analysis defined the theoretically desired locations for the eleven sonic boom stations, shown in figure 3, by a circled number (0-10) and located near the entry ground track shown as a dashed line on the same figure. The predicted overpressure levels at those locations were used to set the signal conditioning amplifiers at each station. Selection of the recommended measurement station locations was based on several considerations. Since the primary objective of the sonic

boom measurement program is to verify the theoretical technique used to predict sonic boom overpressures (ref. 1), the station locations were distributed across the flight Mach number range for which wind-tunnel-measured pressure signatures exist in order to verify the data base. Consequently, the layout of the measurement stations on this flight was designed primarily to confirm the longitudinal trend of overpressure level with Mach number and secondarily, the lateral trend of overpressure with Mach number in the area of expected high overpressures. The majority of the station locations was selected to capture overpressure in the region of maximum predicted overpressure level which occurs in the immediate vicinity of the EAFB lake bed. This selection criteria also has the advantage of locating the measurement stations in the part of the entry groundtrack least affected by atmosphere and trajectory dispersions, thus maximizing the probability of obtaining useful data.

Table I lists the actual final locations for the 11 measurement stations based on the theoretically predicted ground-ray intersection point for flight conditions between Mach 6 and Mach 1.3. Table I also shows nominal peak N-wave overpressure levels that were used as a base from which to set the signal conditioning amplifiers. Theoretical station locations and predicted nominal overpressures were computed based on the final preflight predicted STS-1 Operational Flight Profile (ref. 8) for a nominal entry into EAFB.

Pressure Measurement Instrumentation

The sonic boom data acquisition systems utilized for the Space Shuttle STS-1 reentry sonic boom pressure measurement program is commercially available and is similar to that used in measurements of aircraft sonic boom signatures (ref. 9) and for measurements taken during the Apollo 16 and 17 sonic boom measurement programs (refs. 10 and 11). Eleven data acquisition stations (10 mobile and 1 fixed) were employed along, under, and to the side of the STS-1 entry flight track (see fig. 3). These systems consist of pressure transducers, Dynagages (oscillator detector circuits), signal conditioning amplifiers, FM magnetic tape recorders, and satellite time code receivers. Specifically, the pressure transducer is a commercially available condenser microphone with a high frequency response to 10 kH_z when used with the

model DG-605 Dynagage system, with the low-end frequency response of approximately -5dB at 0.01 H_z. A photograph of a typical data acquisition system is shown in figure 4.

Figure 5 depicts a block diagram of a typical instrumentation system for sonic boom data acquisition. Typically, each measurement station recorded six channels of overpressure data, a time code signal, and voice annotation. The output of the microphones was routed through appropriate signal conditioning amplifiers which allowed various sensitivities for a range of overpressure levels (a precaution necessary to allow for errors in the predictive method or anomalous overpressures caused by unusual atmospheric or focusing conditions.

Figure 6 shows the instrumentation as mounted in commercially available vehicles (vans) with electrical power being furnished by portable gasoline generators.

Atmospheric Soundings

Rawinsonde observations from stations 2 and 4, which were positioned along the STS-1 reentry track 93 and 56 km respectively from the landing site, were taken at approximately 3 hours before and during STS-1 landing on April 14, 1981. Measured values of temperature, wind direction, and speed as a function of altitude are given in tables II and III for observations taken during the STS-1 landing. Balloon data were obtained up to an altitude of about 28 062 meters. Atmospheric data above 28 062 meters are based on a Global Reference Atmosphere obtained from the National Weather Service.

Entry Flight Measurements

Table IV presents measured peak sonic-boom levels (ΔP) obtained at all 11 measurement stations. Also listed in the table for each station are location, coordinates and elevation, and the time at which the sonic boom was recorded. The peak overpressure levels shown are based on the readings, oscillograph traces, and were recorded on channel one of the sonic boom measurement system. This channel was set based on preflight estimates shown in table I and is assumed to be the most accurate and to have the best resolution in the system. This is due to the fact that in general the preflight

levels agreed reasonably well with the measured levels. Qualitatively, all signatures exhibited the features usually seen in typical N-waves. The positive portion of the waves exhibited rapid rise times which increased in time as altitude decreased.

Postflight Sonic Boom Predictions

The purpose of the postflight sonic boom predictions is to compare the measured sonic boom overpressure levels at the 11 measurement stations with the levels that are predicted (ref. 1) for those locations based on the actual flight trajectory.

Preliminary estimates of the predicted sonic boom overpressure levels and locations occurring as a result of the STS-1 Orbiter entry have been calculated. The predictions are preliminary in that only the first available sources of trajectory (primarily limited telemetry data) and meteorological data were used. Flight conditions were input for the same nine Mach numbers that were chosen in the preflight analysis to determine the measurement station locations.

Table V lists the preliminary trajectory parameters for the STS-1 Orbiter entry and indicates those parameters that were measured with a measurement identification number. Meteorological (Rawinsonde) conditions were measured at two measurement station sites near EAFB, Wheeler Ridge and Tehachapi. These data were evaluated and found to be nearly the same; therefore, these preliminary sonic boom predictions were made using the Wheeler Ridge station data (table II). Based on these preliminary trajectory and meteorological data, figure 7 shows the variation of overpressure level with Mach number along the groundtrack. Figures 8 through 16 show the overpressure distribution out to lateral cutoff for each Mach number of interest. In these plots the effect of a left to right bank reversal, occurring between Mach 3.0 and Mach 2.5, is evident as the peak overpressures shift from the right side of the groundtrack to the left. Then, at the lower Mach numbers where the bank angle approaches 0 degrees, the overpressures become more symmetrical about the groundtrack.

The overpressure patterns on the ground, as constructed using the preliminary trajectory data described earlier, are provided in figures 17 and 18.

Figure 17 shows the lateral overpressure contour associated with the Mach +5.9 flight conditions. Figure 18 shows the lateral overpressure contours associated with Mach = 4 to 1.3. Based on these Mach contours, lines of constant overpressure level (isobars) in the vicinity of the entry groundtrack were constructed in order to estimate the overpressure level at each station.

Comparison of Extrapolated Wind Tunnel and Flight Data

Table VI lists the peak theoretical pressure levels determined for each station location and those actually measured at the same station. Peak theoretical values were obtained directly from the isobar contours shown on figures 17 and 18 by superimposing the measurement station coordinates. In general, agreement between measured and theoretical extrapolated levels is good and in particular at the higher Mach numbers and altitudes (stations 0-5). The exception being stations 6, 9, and 10, which are higher by 19.2, 33.5, and 23.9 N/m^2, respectively, than the theoretically predicted levels. It should be noted that because of the preliminary nature of both the theoretical and measured data some disagreement is to be expected.

CONCLUDING REMARKS

Preliminary peak sonic boom levels recorded at 11 measurement stations during the descent of the Orbiter Columbia during the STS-1 mission are presented. Peak overpressure levels ranging from 33.5 N/m^2 to 114.9 N/m^2 were observed during reentry for altitudes from about 38 415 to 19 207 meters, respectively. The signatures were simple N-waves exhibiting rapid rise times. Theoretical predicted values of the peak sonic boom overpressure levels made by utilizing semi-empirical techniques correlated well with the measurements. Follow-on work will include detailed signature analysis of all the measured data and further postflight predictions using well conditioned flight parameter data. It is expected that in the final theoretical analysis, using ray tracing techniques, definite conclusions will be reached with respect to the correlation between flight-measured and predicted signature characteristics.

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TABLE I.- STS-1 PREFLIGHT SONIC BOOM PREDICTIONS

STATION	MACH NUMBER	LATERAL DISTANCE FROM THE GROUND-TRACK (KM)	CALCULATED PEAK OVERPRESSURES N/m^2	STATION COORDINATES (DEG:MIN:SEC) AND ELEVATIONS (METERS)
0	5.89	0	38.3	35:50:00 NORTH 120:45:00 WEST 202
1	4.02	0	51.2	35:09:38 NORTH 119:20:29 WEST 116
2	3.50	0	48.8	35:04:50 NORTH 118:57:29 WEST 148
3	2.97	0	64.2	35:05:00 NORTH 118:39:00 WEST 1152
4	2.45	0	73.7	35:04:10 NORTH 118:19:30 WEST 1402
5	2.04	0	86.7	35:01:53 NORTH 118:06:45 WEST 811
6	1.83	0	94.8	35:00:21 NORTH 118:00:45 WEST 750
7	1.52	0	102	34:58:35 NORTH 117:52:25 WEST 671
8	1.52	10.54	88.6	34:51.38 NORTH 117:52:32 WEST 695
9	1.52	10.54	85.7	35:02:39 NORTH 117:47:24 WEST 693
10	1.31	0	89.5	34:55:42 NORTH 117:47:24 WEST 777

TABLE II.- WHEELER RIDGE MET DATA (1815 GMT, 14 APR)

HEIGHT GPM	TEMP DG C	DIR DG	SPEED M/SEC	HEIGHT GPM	TEMP DG C	DIR DG	SPEED M/SEC
168.0	22.6	330.0	.5	4606.8	-6.7	176.9	5.3
194.0	21.4	286.7	.5	4727.8	-7.6	186.9	4.6
281.0	20.3	283.3	.7	4836.8	-7.9	199.7	4.2
368.5	19.2	280.9	.9	4960.9	-8.8	206.6	4.5
465.4	17.9	287.5	1.0	5072.7	-9.4	208.8	4.9
563.1	17.1	291.7	.7	5185.7	-10.4	208.4	5.0
652.6	16.3	257.8	.2	5314.3	-11.7	205.2	4.8
751.8	15.4	198.2	.6	5429.9	-12.8	203.3	4.3
842.9	15.0	169.6	.3	5546.8	-13.9	204.1	4.0
934.8	14.6	92.7	.2	5665.1	-14.8	206.1	3.7
1027.6	14.3	122.1	.2	5784.8	-15.6	204.4	3.4
1121.3	13.9	194.9	2.2	5905.9	-17.1	194.7	3.3
1215.9	13.5	167.4	3.4	6028.5	-17.8	186.0	3.2
1321.2	13.9	151.3	4.9	6152.8	-18.5	184.4	2.6
1418.5	15.9	132.8	7.2	6278.7	-19.7	191.2	1.4
1517.1	15.6	134.5	8.0	6406.1	-21.0	183.7	1.4
1606.7	14.8	134.9	8.3	6535.2	-21.8	192.3	1.1
1707.0	13.9	133.4	7.8	6649.6	-23.0	220.8	.6
1808.2	13.1	131.3	7.3	6781.9	-24.4	255.8	.5
1910.3	12.3	129.0	7.8	6899.0	-25.8	290.3	.7
2013.5	11.9	128.5	8.2	7034.4	-27.1	303.6	1.1
2117.7	10.4	127.7	8.4	7154.4	-28.2	310.3	1.5
2222.7	9.5	125.9	8.5	7275.9	-29.4	301.9	1.2
2328.7	8.8	125.4	8.7	7399.0	-30.3	226.1	.9
2425.0	7.5	126.5	8.7	7541.7	-31.5	209.7	1.6
2533.0	7.3	126.5	9.1	7668.4	-32.3	223.7	2.3
2642.1	5.9	127.3	9.3	7797.0	-32.9	235.6	3.0
2741.2	4.7	128.5	9.0	7927.6	-33.9	242.1	3.5
2852.2	3.9	132.4	8.4	8060.1	-35.0	248.4	3.7
2953.1	3.0	140.0	8.7	8175.1	-36.4	256.8	3.7
3055.1	3.0	146.9	9.6	8310.9	-37.5	263.6	3.5
3169.8	2.2	153.3	10.3	8448.8	-38.8	267.8	3.1
3274.1	1.4	160.6	9.9	8568.6	-40.2	265.1	3.0
3379.5	.7	167.3	8.4	8710.3	-41.0	258.5	3.3
3486.1	.6	166.6	7.4	8833.7	-41.9	256.8	3.9
3606.1	-.1	165.1	6.2	8979.9	-43.2	263.4	4.6
3703.0	-1.2	162.5	5.1	9107.0	-44.3	270.3	5.6
3813.1	-2.2	159.9	4.6	9236.2	-44.9	266.9	6.6
3924.3	-3.1	156.0	4.3	9367.4	-46.0	258.7	7.2
4036.8	-4.0	149.3	4.3	9523.2	-46.9	254.0	7.7
4150.5	-4.8	147.4	4.7	9659.0	-48.2	254.0	8.0
4265.6	-5.1	153.1	5.4	9796.9	-49.2	257.0	8.1
4382.2	-5.5	161.5	6.0	9913.5	-50.4	261.1	8.3
4500.4	-6.1	168.6	6.0	10055.7	-51.0	268.4	8.8
				10200.4	-52.1	276.1	9.4

TABLE II.- Concluded.

HEIGHT GPM	TEMP DG	DIR DG	SPEED M/SEC	HEIGHT GPM	TEMP DG C	DIR DG	SPEED M/SEC
10347.8	-53.2	284.3	9.7	18171.2	-58.2	253.9	8.3
10472.7	-54.0	288.5	9.7	18428.3	-58.1	247.1	4.6
10625.2	-55.1	288.6	9.4	18606.6	-56.1	212.6	4.3
10754.5	-55.7	287.6	9.3	18885.0	-56.2	206.4	7.2
10912.9	-56.4	290.2	9.3	19176.0	-56.4	206.6	9.3
11047.3	-57.4	291.1	9.6	19377.4	-56.7	209.8	9.7
11212.0	-57.9	285.0	9.9	19691.1	-57.7	207.9	6.3
11352.2	-58.8	273.5	11.1	19909.1	-56.9	213.7	6.5
11524.0	-59.3	268.3	12.5	20251.7	-56.7	233.3	4.8
11670.7	-59.5	271.6	13.2	20490.9	-56.9	248.3	2.1
11820.7	-59.8	278.9	12.9	20866.9	-57.4	180.2	2.7
11943.2	-59.8	282.9	11.1	21131.2	-55.7	96.2	3.1
12099.5	-60.7	275.0	9.6	21408.0	-56.1	147.6	1.1
12259.5	-60.9	260.3	9.9	21847.0	-55.7	269.9	.8
12423.8	-60.3	251.3	11.4	22318.0	-56.6	101.9	7.1
12558.8	-59.5	248.0	12.0	22653.4	-54.8	79.1	9.9
12732.2	-59.5	246.8	11.9	23195.1	-54.1	27.9	6.4
12874.4	-59.6	245.7	11.9	23584.4	-53.7	52.6	8.3
13057.0	-59.1	243.4	12.5	24002.1	-50.7	44.8	8.6
13207.7	-57.7	241.2	12.6	24692.1	-48.5	51.4	9.8
13362.5	-57.7	239.7	12.4	25199.0	-48.0	55.3	13.0
13521.7	-56.7	239.6	12.6	26043.6	-47.2	41.2	10.0
13685.0	-57.4	240.9	12.9	26669.9	-50.4	30.2	8.9
13852.4	-57.6	241.6	12.7	27741.4	-45.7	353.1	8.5
14024.3	-57.4	238.5	12.8	29045.9	-41.8	331.8	10.4
14200.9	-57.7	233.9	13.5	30500.0	-40.3	120.6	.5
14382.5	-57.7	229.3	14.7	32300.0	-36.1	296.6	.5
14569.3	-58.2	228.6	15.5	34100.0	-32.0	298.3	1.5
14761.5	-58.2	230.3	15.6	36000.0	-27.7	297.1	2.3
14909.3	-59.3	233.5	15.1	37800.0	-23.4	295.5	2.9
15111.9	-58.2	234.5	13.6	39600.0	-19.1	294.5	3.5
15268.9	-57.4	229.7	13.9	41500.0	-14.3	270.9	3.7
15485.0	-57.4	227.5	16.5	43300.0	-9.4	247.1	4.5
15652.3	-56.7	228.9	16.5	45100.0	-5.0	233.6	5.8
15824.7	-56.1	232.4	15.6	46900.0	-3.8	243.4	6.2
16062.0	-56.7	234.0	14.7	48800.0	-2.6	251.8	6.7
16245.8	-56.7	231.5	12.4	50600.0	-2.6	254.3	6.7
16434.8	-57.4	223.8	11.3	52400.0	-5.4	244.8	5.4
16628.9	-58.1	218.4	12.0	54300.0	-8.0	230.3	4.4
16828.1	-59.8	220.4	13.8	56100.0	-12.0	208.4	4.1
17032.5	-60.9	225.0	16.2	57900.0	-17.0	186.1	4.5
17243.3	-60.9	230.4	15.7	59700.0	-22.1	169.8	5.5
17461.9	-60.2	237.3	12.6	61600.0	-26.9	165.0	4.1
17689.2	-59.5	237.3	12.1	63400.0	-31.8	156.7	2.4
17925.2	-59.8	241.8	11.3	65200.0	-36.7	135.9	.9

TABLE III.- TEHACHAPI MET DATA (1818 GMT, 14 APR)

HEIGHT GPM	TEMP DG C	DIR DG	SPEED M/SEC	HEIGHT GPM	TEMP DG C	DIR DG	SPEED M/SEC
1366.0	21.0	150.0	6.2	6166.2	-19.4	193.5	2.5
1473.8	18.8	114.9	6.6	6292.3	-21.0	190.1	1.8
1574.0	16.7	113.3	6.6	6420.1	-21.6	200.1	.8
1674.6	14.6	110.0	6.4	6533.3	-22.9	296.9	.2
1775.9	13.3	106.6	6.3	6647.7	-24.1	348.4	.4
1867.7	12.3	109.7	6.6	6780.2	-25.0	345.9	.5
1970.5	11.5	114.4	7.0	6897.5	-26.3	322.4	.6
2074.4	10.4	119.4	7.5	7033.3	-27.5	302.6	1.0
2168.6	9.7	120.1	8.7	7153.8	-28.3	302.4	1.6
2274.3	8.9	117.9	9.1	7275.9	-29.2	299.2	1.9
2391.8	7.9	117.2	9.9	7399.6	-30.3	276.4	1.7
2488.8	7.0	117.0	10.6	7524.9	-31.5	248.9	1.9
2597.6	5.8	117.9	11.1	7651.8	-32.7	235.9	2.2
2696.3	4.7	116.4	11.5	7780.5	-33.6	239.2	2.5
2807.1	3.9	114.0	11.9	7910.9	-35.0	240.4	2.8
2907.7	2.7	112.8	11.3	8043.1	-36.2	242.6	3.3
3020.5	1.7	112.0	10.9	8177.2	-37.2	245.8	3.7
3111.6	.7	112.1	10.8	8293.8	-38.3	248.5	3.9
3215.0	.1	118.1	10.0	8431.6	-39.6	252.3	3.9
3331.1	-.2	130.6	8.9	8551.4	-40.4	257.0	3.7
3425.2	-.4	145.6	8.6	8693.3	-41.7	264.4	3.7
3544.1	-1.5	148.5	9.4	8837.3	-43.1	266.9	3.8
3652.4	-1.8	150.8	9.7	8962.7	-44.0	260.1	4.1
3749.8	-2.0	153.0	9.6	9089.8	-45.2	253.8	4.6
3860.6	-2.8	157.4	9.3	9218.7	-46.3	253.5	5.4
3972.7	-3.4	160.1	9.1	9371.8	-47.0	262.4	6.2
4086.0	-4.6	164.0	8.8	9505.4	-47.8	270.1	7.3
4200.5	-5.5	169.1	8.0	9641.2	-48.6	274.1	8.4
4303.5	-5.8	173.3	7.2	9779.3	-49.8	273.8	9.6
4420.7	-6.6	178.9	6.0	9919.8	-50.6	271.2	10.6
4526.2	-7.0	182.7	5.3	10062.7	-51.6	270.4	11.1
4646.3	-7.6	192.3	4.0	10208.1	-52.9	273.2	11.6
4754.3	-8.8	203.1	3.2	10331.3	-53.7	277.3	11.8
4877.1	-10.0	206.6	3.0	10481.6	-54.8	283.7	11.7
4987.5	-10.7	206.5	3.1	10609.1	-55.4	288.1	11.8
5099.1	-12.0	202.9	3.5	10764.9	-56.4	288.3	12.0
5226.2	-12.5	199.3	3.9	10897.3	-57.1	286.1	12.0
5340.7	-13.1	205.7	3.8	11032.3	-57.1	283.9	11.7
5456.6	-14.1	209.7	3.9	11197.7	-58.1	281.1	10.5
5573.8	-15.0	214.8	4.0	11338.7	-58.1	277.6	9.4
5692.4	-16.1	220.2	4.0	11482.7	-58.4	273.7	8.6
5812.4	-17.4	220.8	3.9	11630.0	-58.4	271.5	8.5
5933.9	-17.9	211.6	3.5	11780.8	-58.6	270.1	9.0
6057.0	-18.7	201.5	3.0	11904.1	-58.6	268.2	9.6
				12061.5	-58.8	267.0	11.0

TABLE III.- Concluded

HEIGHT GPM	TEMP DG C	DIR DG	SPEED M/SEC	HEIGHT GPM	TEMP DG C	DIR DG	SPEED M/SEC
12223.0	-58.8	265.9	13.0	21639.3	-56.9	192.5	3.8
12388.6	-58.9	264.9	15.9	21941.8	-55.7	112.3	2.5
12524.3	-58.9	264.5	17.7	22259.8	-56.4	23.1	3.3
12698.1	-58.9	262.9	17.3	22770.3	-54.5	65.3	7.4
12840.7	-59.1	257.0	15.8	23136.7	-54.1	99.9	5.9
13023.5	-59.1	249.7	14.8	23730.4	-53.3	56.9	7.3
13173.9	-58.4	246.1	14.2	24163.5	-49.5	65.5	10.1
13328.4	-58.1	244.3	13.9	24879.8	-48.9	60.9	10.9
13486.9	-57.9	241.5	13.8	25405.8	-48.6	58.1	16.0
13649.4	-58.6	238.2	14.2	25978.6	-48.2	50.2	10.6
13816.1	-58.1	236.2	15.4	26944.4	-48.3	41.5	12.7
13987.5	-58.1	236.1	16.6	27680.1	-46.3	20.7	9.7
14163.6	-58.4	236.3	17.1	29600.0	-42.4	112.5	1.2
14344.4	-59.1	234.9	16.8	31400.0	-38.2	161.6	.0
14483.1	-59.3	232.8	17.0	33200.0	-34.1	297.9	1.0
14672.9	-59.5	231.5	17.9	35100.0	-29.9	298.3	1.9
14868.9	-58.8	230.6	18.3	36900.0	-25.6	296.2	2.6
15020.3	-58.4	231.9	18.7	38700.0	-21.3	295.0	3.2
15229.1	-56.7	235.1	17.5	40500.0	-16.8	285.7	3.6
15390.7	-57.2	234.2	15.7	42400.0	-11.8	257.8	4.0
15612.4	-57.7	228.7	15.7	44200.0	-7.3	238.7	5.1
15783.9	-57.4	225.3	17.0	46000.0	-4.4	238.7	6.0
15960.3	-57.4	226.3	19.0	47900.0	-3.2	247.8	6.4
16141.7	-57.4	229.3	20.1	49700.0	-1.9	255.4	7.0
16391.6	-58.1	230.1	19.6	51500.0	-4.0	250.0	6.1
16585.0	-59.1	228.1	18.1	53300.0	-6.7	238.3	4.9
16783.4	-60.7	222.7	16.6	55200.0	-9.5	220.4	4.1
16987.3	-60.9	217.8	16.7	57000.0	-14.5	196.8	4.2
17198.9	-59.3	218.4	19.6	58800.0	-19.5	177.1	4.9
17418.4	-60.0	223.0	20.8	60700.0	-24.5	166.8	5.0
17645.9	-59.3	228.0	17.5	62500.0	-29.4	162.0	3.3
17802.9	-58.2	233.8	11.3	64300.0	-34.2	146.2	1.6
18046.5	-58.4	233.5	11.5	66100.0	-39.1	214.8	.6
18299.4	-59.1	244.0	14.2	68000.0	-43.9	264.9	2.2
18562.8	-58.6	250.4	12.7	69800.0	-49.0	271.3	4.1
18745.2	-58.2	233.7	10.0	71600.0	-53.3	314.3	1.8
19029.9	-57.2	215.2	9.6	73500.0	-57.6	40.5	3.3
19227.7	-56.9	211.7	9.8	75300.0	-61.9	57.2	6.2
19536.4	-57.4	208.3	9.5	77100.0	-65.7	73.3	6.6
19750.6	-57.4	214.6	8.6	78900.0	-69.3	86.7	7.5
20086.0	-57.7	222.1	7.8	80800.0	-72.5	111.8	7.5
20319.5	-58.1	224.8	7.8	82600.0	-75.2	153.0	9.4
20686.1	-58.8	231.1	7.6	84400.0	-77.9	173.6	14.1
20942.6	-58.4	217.6	2.2	86300.0	-80.0	193.2	14.2
21211.6	-56.4	198.2	3.2	88100.0	-82.0	219.4	14.2

TABLE IV.- SONIC BOOM STATION LOCATIONS AND MEASURED OVERPRESSURE LEVELS

STATION	STATION LOCATION	STATION COORDINATES (DEG:MIN:SEC) AND ELEVATIONS (METERS)	PEAK OVERPRESSURES (N/m^2)	BOOM ARRIVAL TIME GREENWICH MEAN TIME HR:MIN:SEC (DAY 104)
0	CAMP ROBERTS (PASO ROBLES)	35:50:00 NORTH 120:45:00 WEST 202	33.5	18:13:28.431
1	TAFT	35:09:38 NORTH 119:20:29 WEST 116	52.7	18:14:47.579
2	WHEELER RIDGE	35:04:50 NORTH 118:57:29 WEST 148	43.1	18:15:08.729
3	STALLION SPRINGS	35:05:00 NORTH 118:39:00 WEST 1152	52.7	18:15:29.283
4	CAMRON CANYON	35:04:10 NORTH 118:19:30 WEST 1402	67.0	18:15:54.266
5	MOJAVE	35:01:53 NORTH 118:06:45 WEST 811	71.8	18:16:20.651
6	EAST MOJAVE	35:00:21 NORTH 118:00:45 WEST 750	114.9	18:16:33.797
7	NORTH BASE	34:58:35 NORTH 117:52:25 WEST 671	95.8	18:16:54.366
8	SOUTH BASE	34:51:38 NORTH 117:52:32 WEST 695	81.4	18:17:11.449
9	NORTH EDWARDS	35:02:39 NORTH 117:47:24 WEST 693	110.1	18:17:08.634
10	ROCKET BASE	34:55:42 NORTH 117:47:24 WEST 777	91.0	18:17:17.103

TABLE V.- STS-1 POSTFLIGHT DESCENT FLIGHT CONDITIONS FOR SONIC BOOM OVERPRESSURE CALCULATIONS

GREENWICH MEAN TIME HRS:MIN:SEC DAY 104	MACH NUMBER (V95L3029C)	ALTITUDE METERS (V95H0175C)	RELATIVE AZIMUTH* DEG (V98U1597C)	FLIGHT PATH ANGLE DEG (V95H0261C)	MACH RATE 1/SEC	HEADING RATE DEG/SEC	FLIGHT PATH ANGLE RATE DEG/SEC	LONGITUDE WEST DEG	LATITUDE NORTH DEG	ANGLE OF ATTACK DEG (V95H3021C)	BANK ANGLE DEG (V90H2202C)
18:11:29.1	5.89	38 445	127	-2.49	-0.021	0.327	-0.009	120.61	35.825	24.9	46.3
18:12:58.0	4.02	32 890	103	-2.55	-.018	-.632	-.118	119.35	35.205	20.3	-54.0
18:13:25.7	3.50	30 567	96	-4.50	-.018	-.404	-.023	119.06	35.080	18.9	-37.5
18:13:55.4	2.97	28 055	85	-5.20	-.017	-.518	-.030	118.75	35.022	16.5	-39.8
18:14:31.2	2.45	25 619	88	-4.64	-.052	.212	.054	118.43	35.037	13.0	15.5
18:14:54.9	2.04	24 317	99	-6.39	-.014	.514	-.178	118.25	35.040	10.9	29.0
18:15:13.7	1.83	22 805	105	-9.36	-.003	.348	-.130	118.13	35.028	9.9	18.5
18:15:39.7	1.52	20 232	110	-11.05	-.010	.160	-.017	118.00	35.000	8.9	7.2
18:15:50.8	1.31	19 201	110	-11.65	-.020	.126	-.074	117.96	34.990	8.2	4.9

* Corrected to true North.

( ) Indicates flight measurement identification number.

TABLE VI.- PRELIMINARY COMPARISON OF CALCULATED AND MEASURED STS-1 ENTRY SONIC BOOM OVERPRESSURES

STATION	MACH NUMBER	OVERPRESSURES, N/m^2	
		COMPUTED	MEASURED
0	5.9	38.3	33.5
1	4.0	47.9	52.7
2	3.5	52.7	43.1
3	3.0	52.7	52.7
4	2.5	62.2	67.0
5	2.0	76.6	71.8
6	1.8	95.8	114.9
7	1.5	95.8	95.8
8	1.5	86.2	81.4
9	1.5	76.6	110.1
10	1.3	67.0	91.0

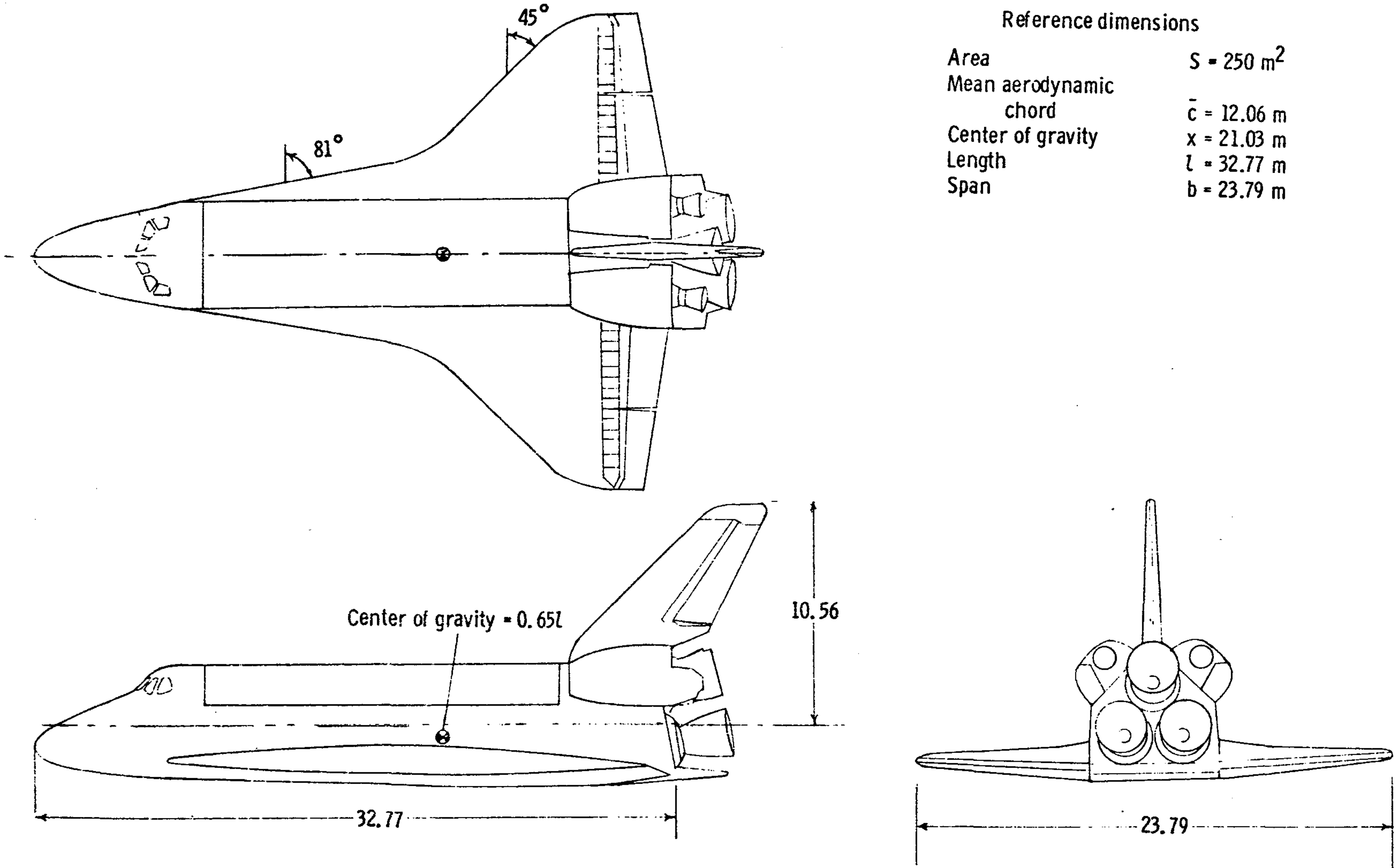

Figure 1.- Schematic of Orbiter configuration.

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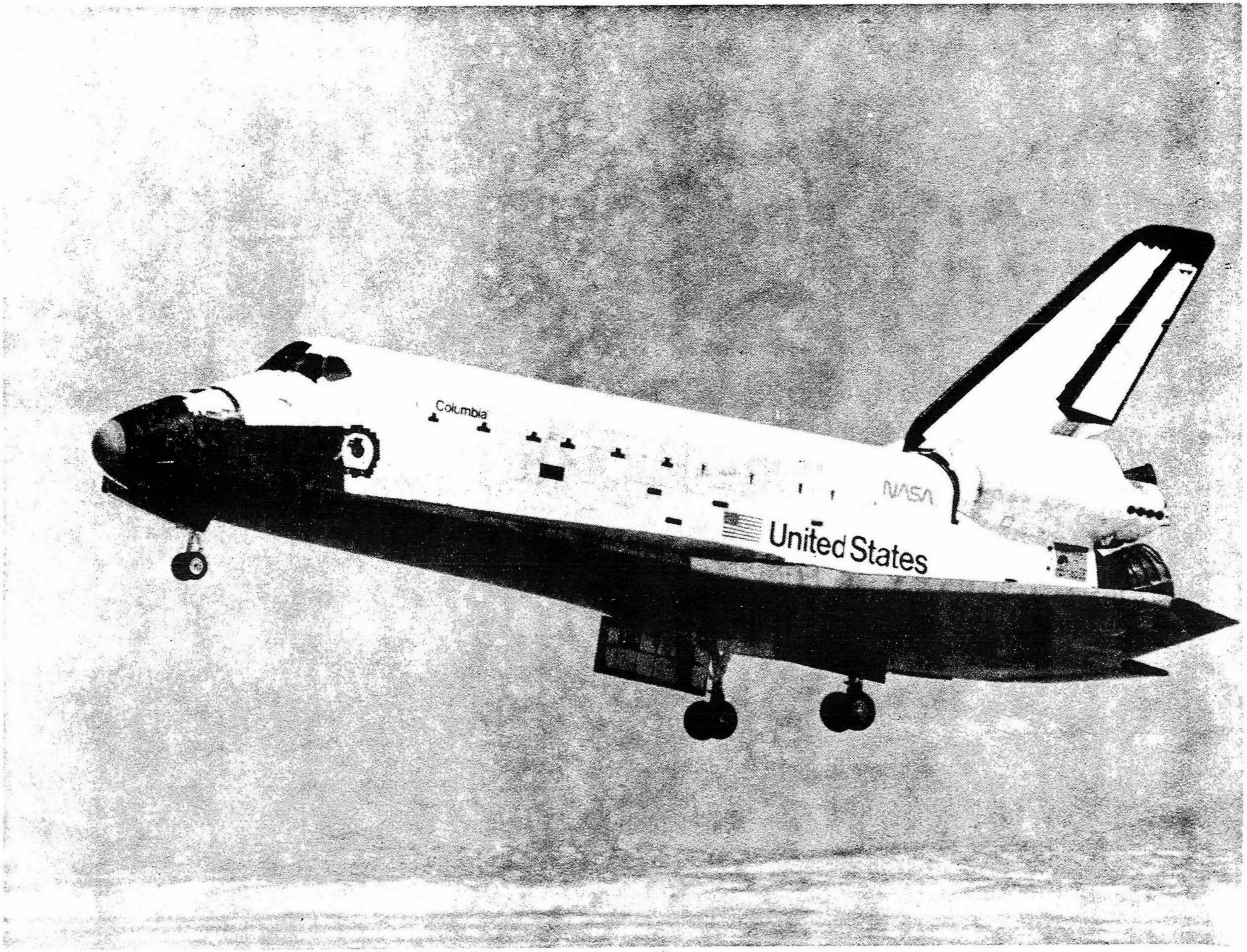

Figure 2.- Orbiter Columbia in descending flight during STS-1 mission.

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L-81-1431

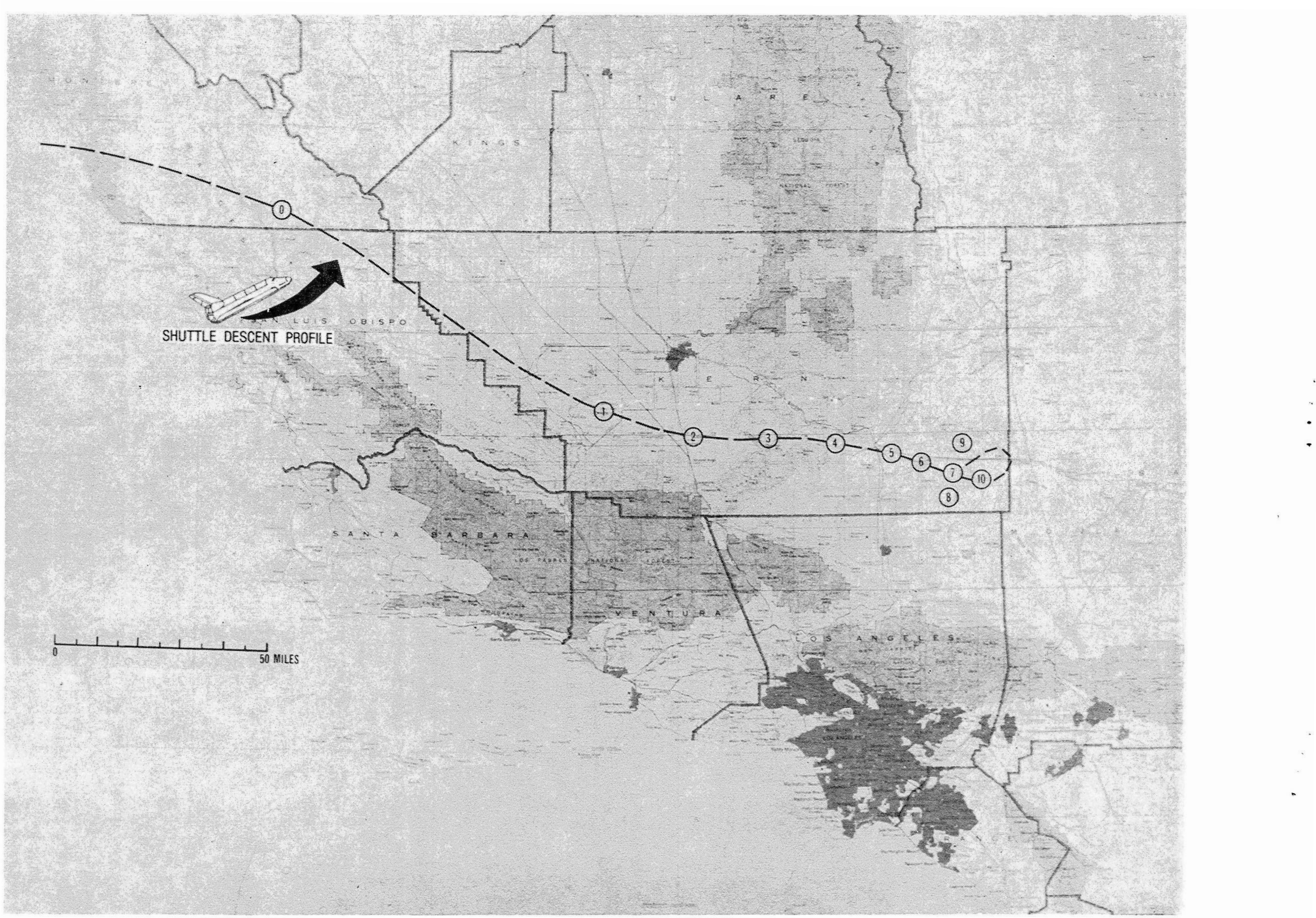

Figure 3.- STS-1 Reentry track and measurement stations.

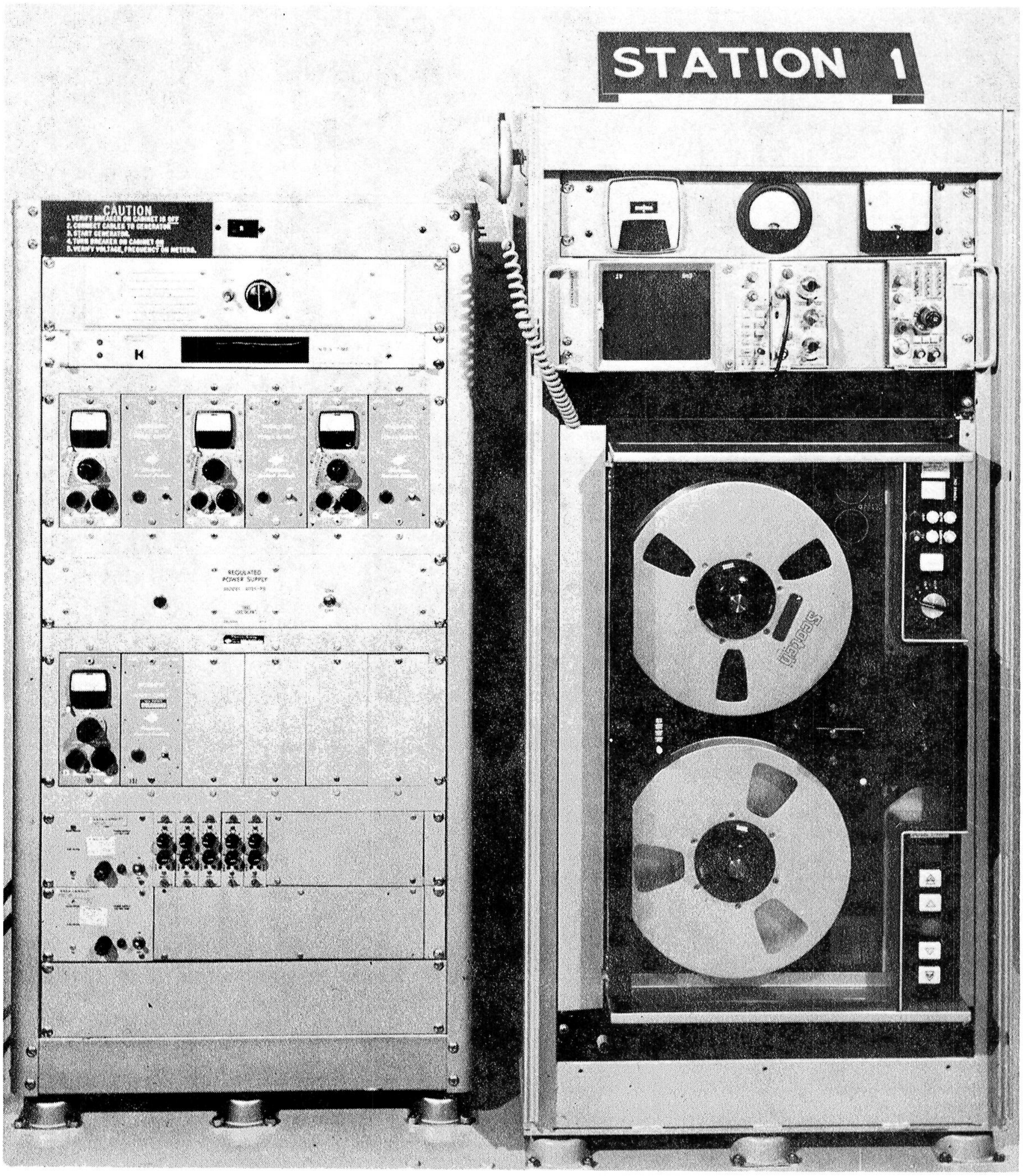

Figure 4.- Typical sonic boom data acquisition system.

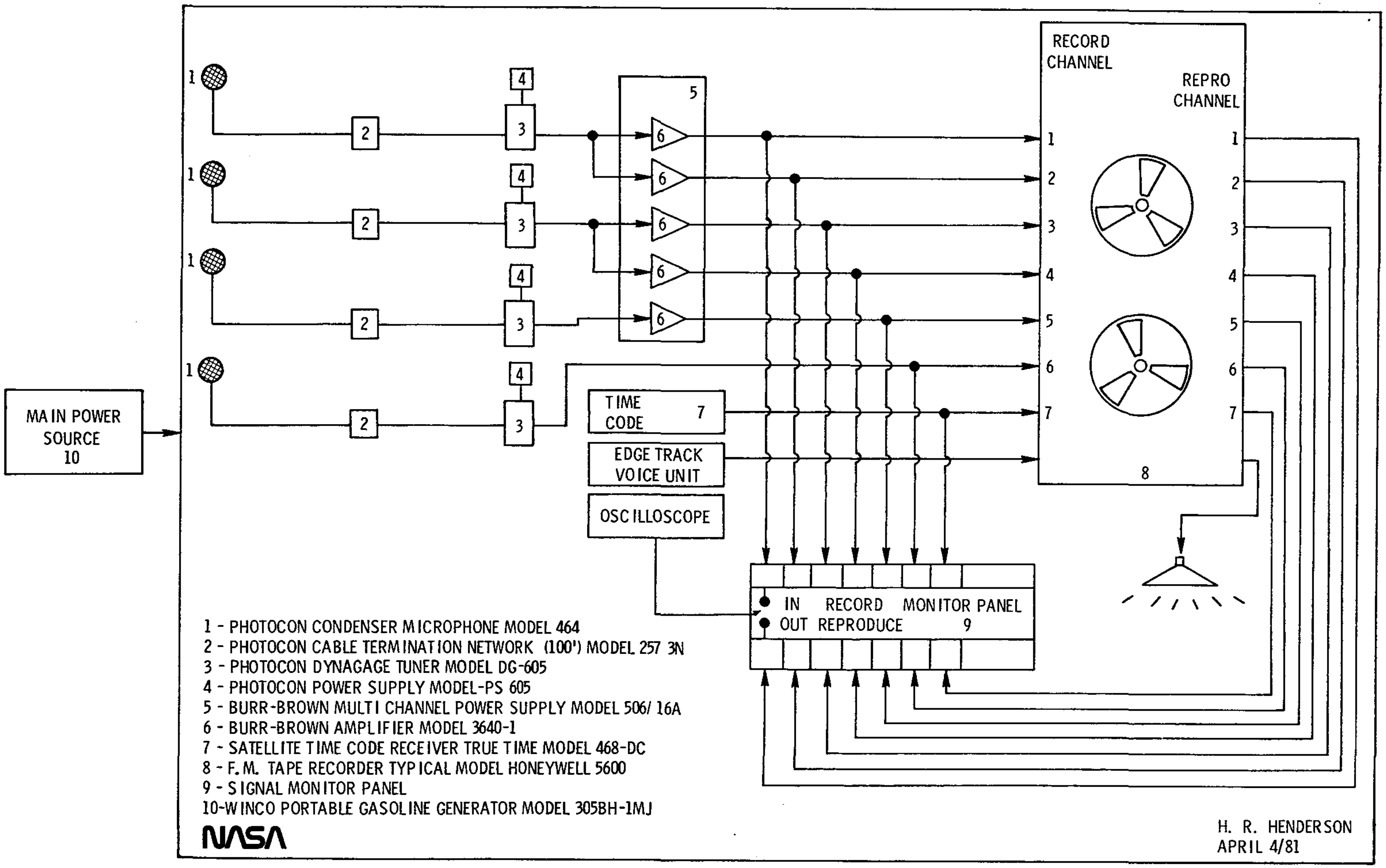

Figure 5.- Block diagram showing typical sonic boom data acquisition system.

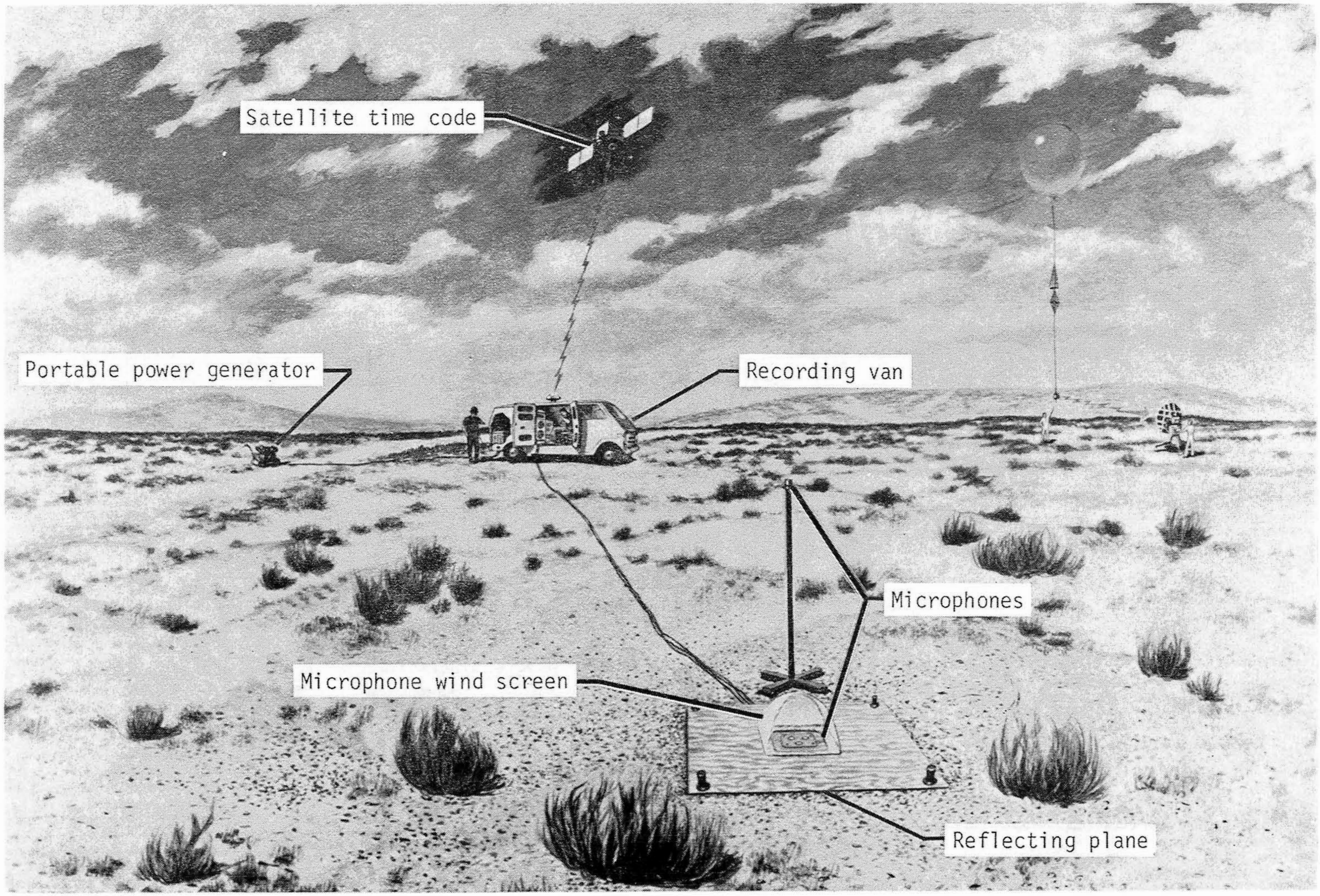

Figure 6.- Typical mobile data acquisition station, associated microphone array and satellite timing system.

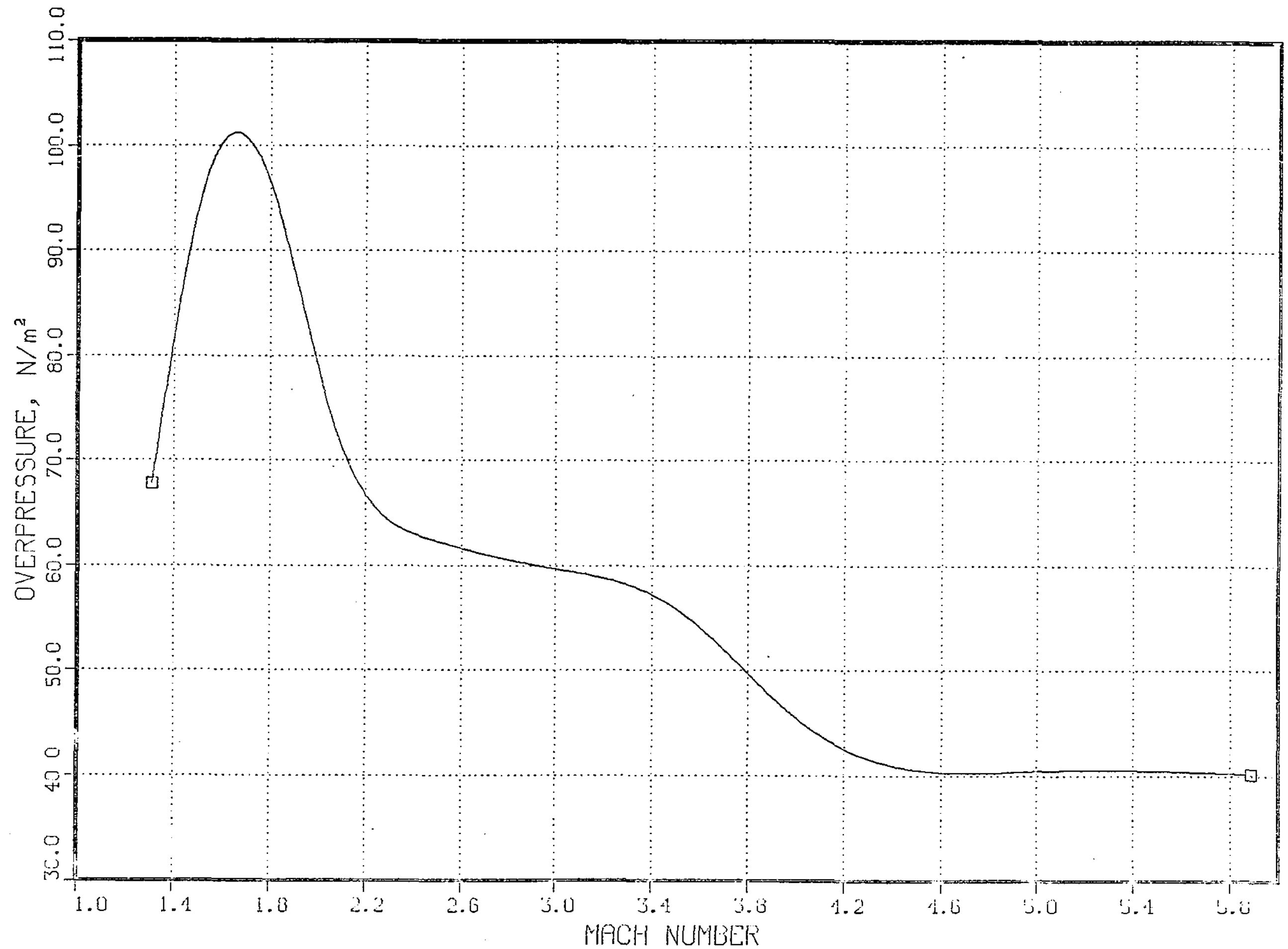

Figure 7.- Variation of overpressure level with Mach number along the entry groundtrack.

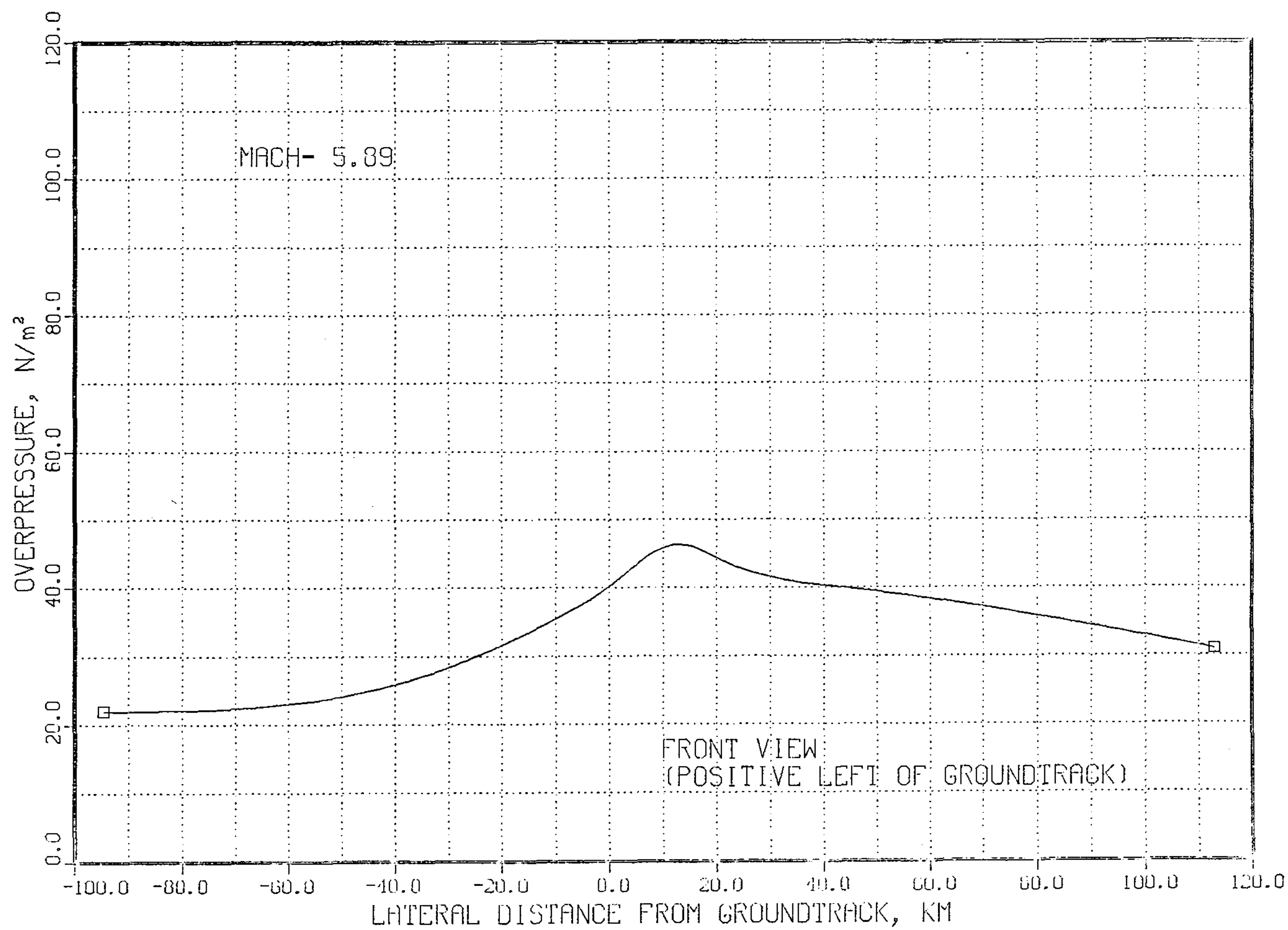

Figure 8.- Lateral distribution of overpressure level (Mach number = 5.89).

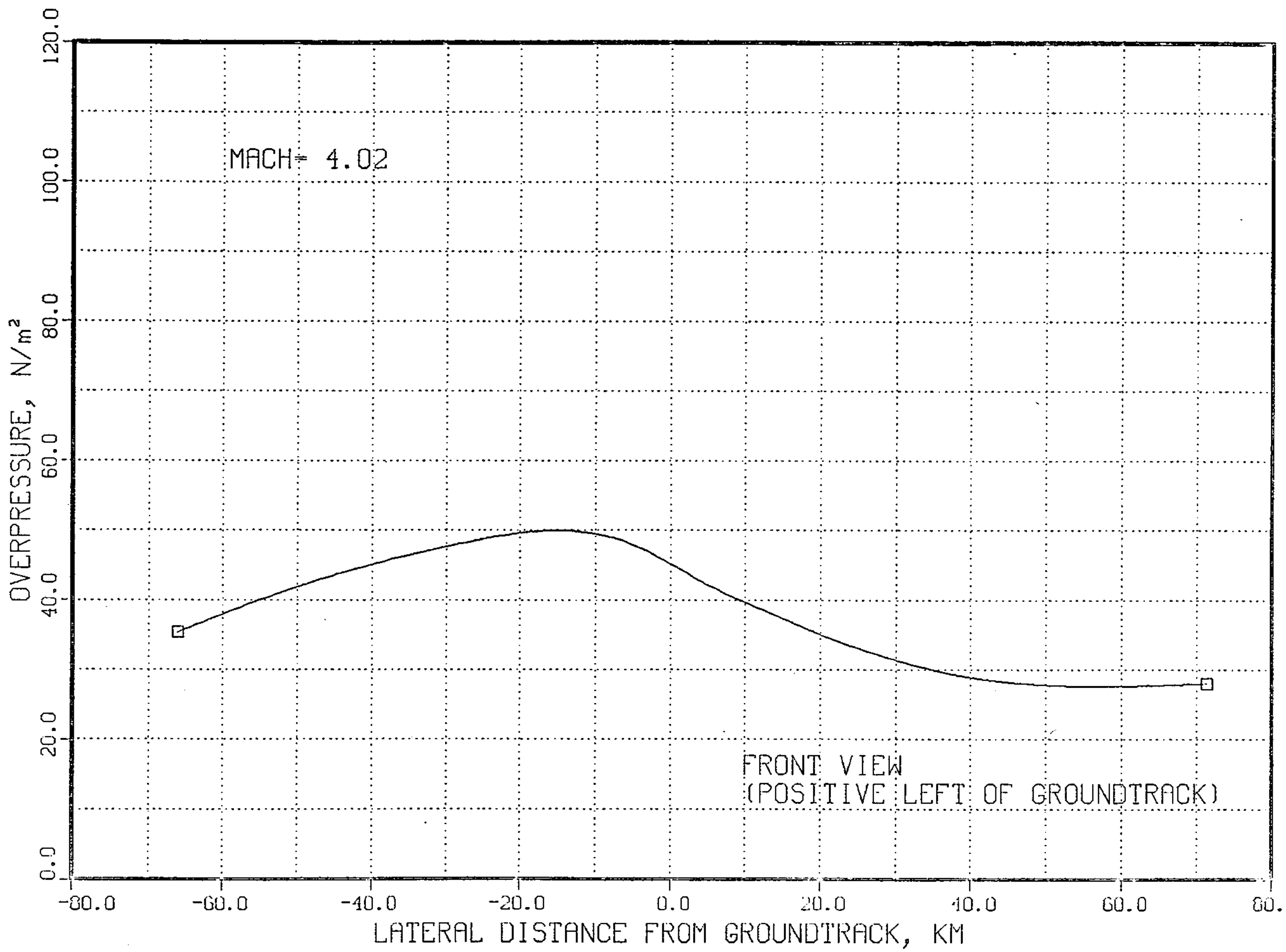

Figure 9.- Lateral distribution of overpressure level (Mach number = 4.02).

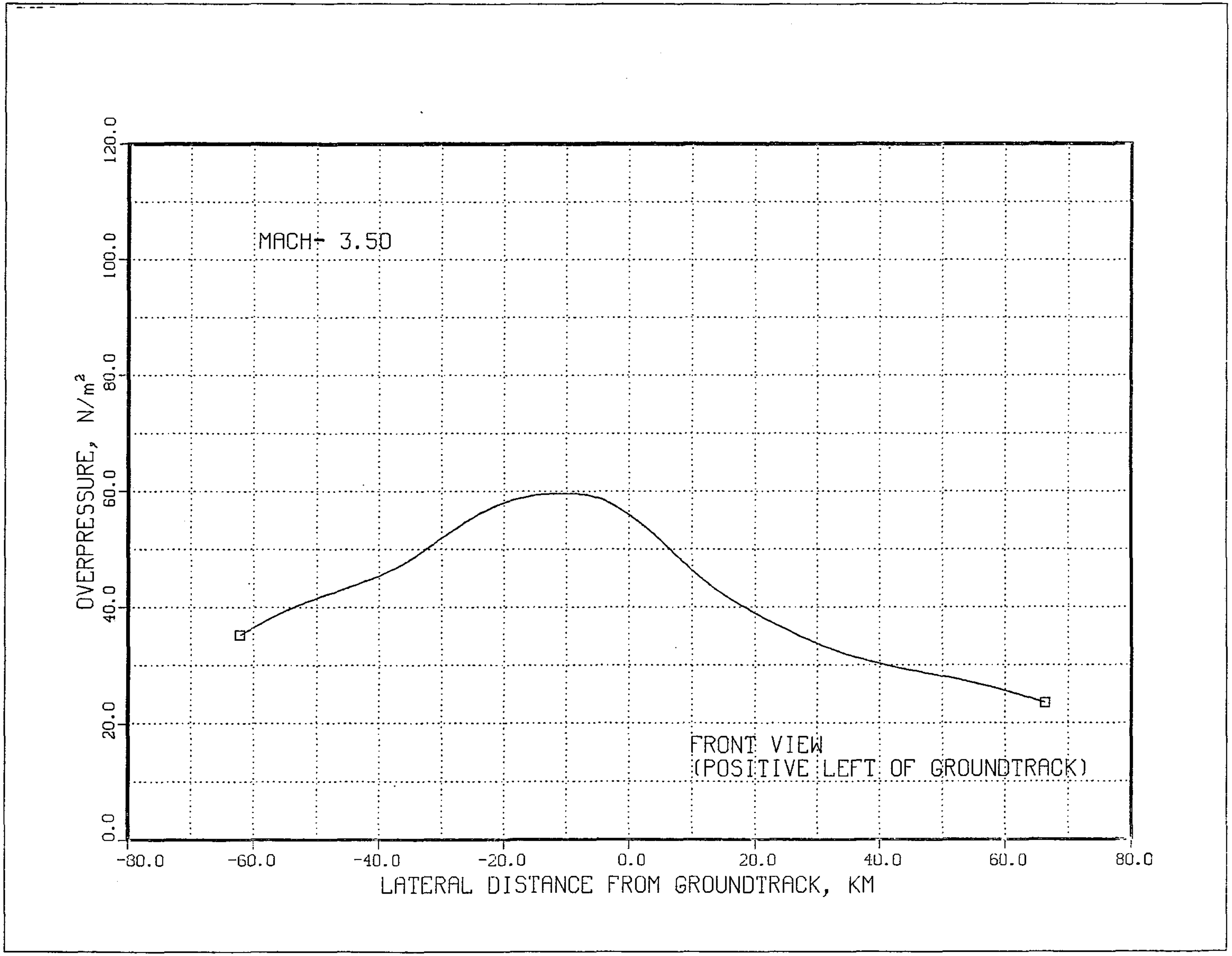

Figure 10.- Lateral distribution of overpressure level (Mach number = 3.50).

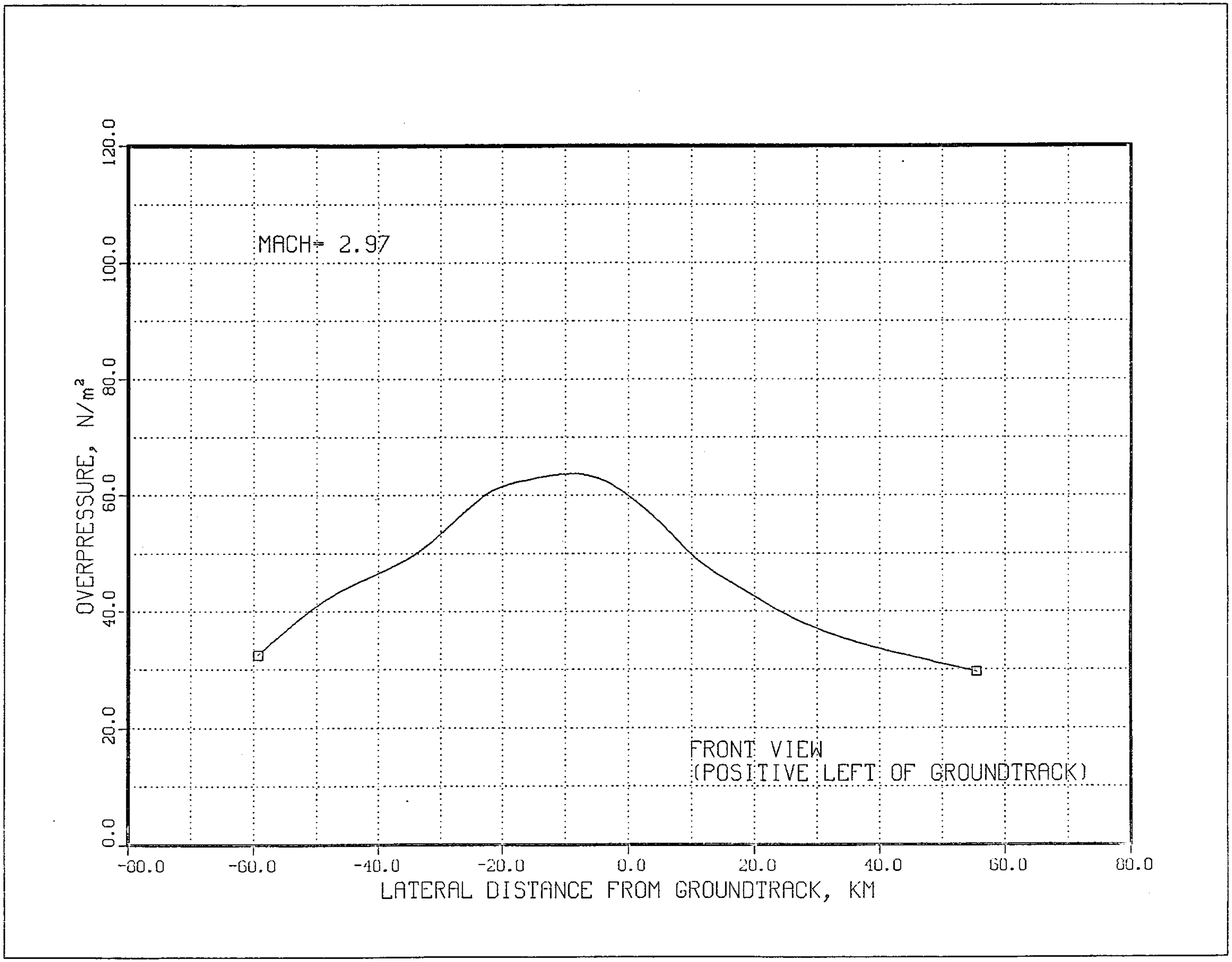

Figure 11.- Lateral distribution of overpressure level (Mach number = 2.97).

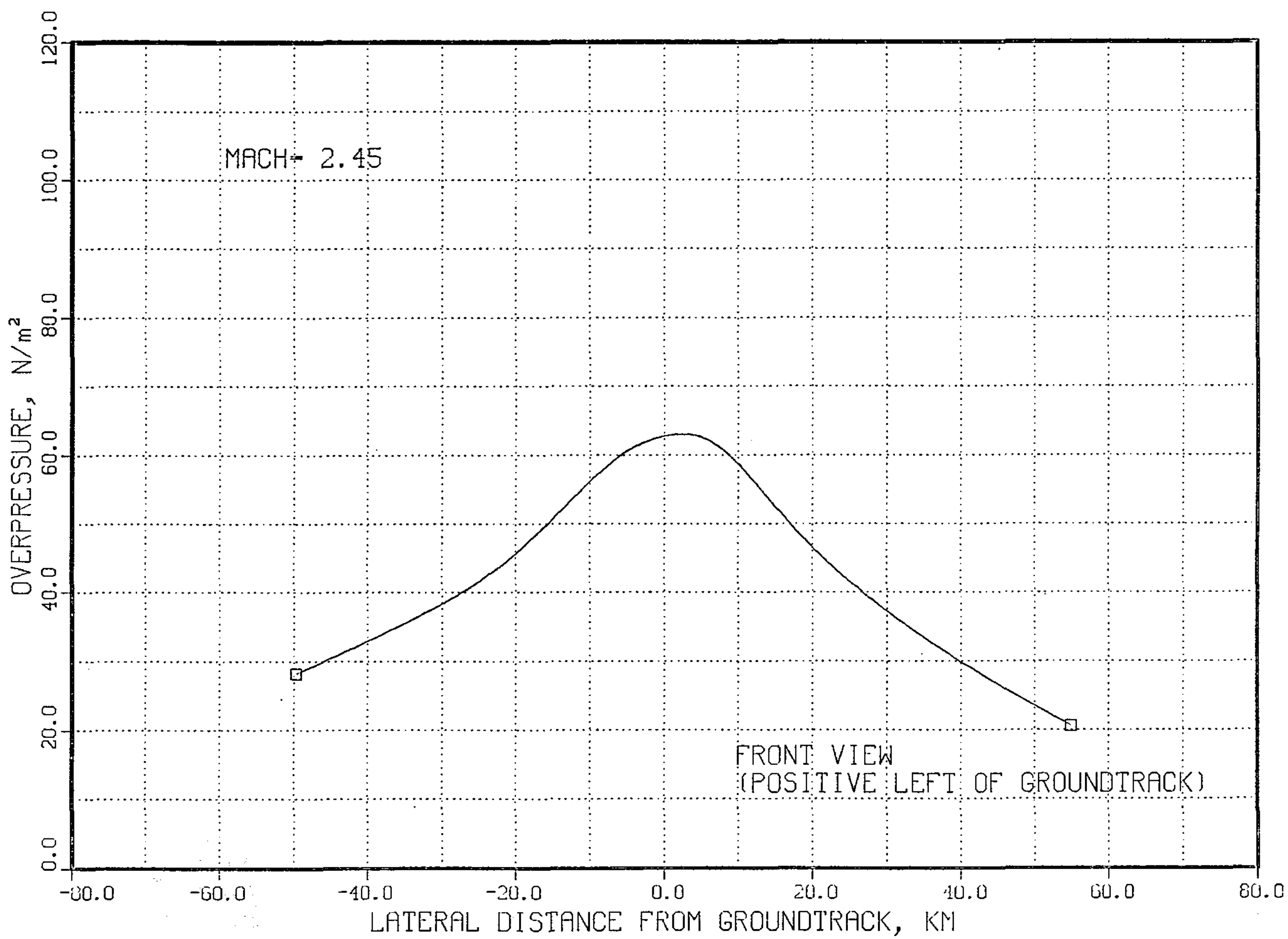

Figure 12.- Lateral distribution of overpressure level (Mach number = 2.45).

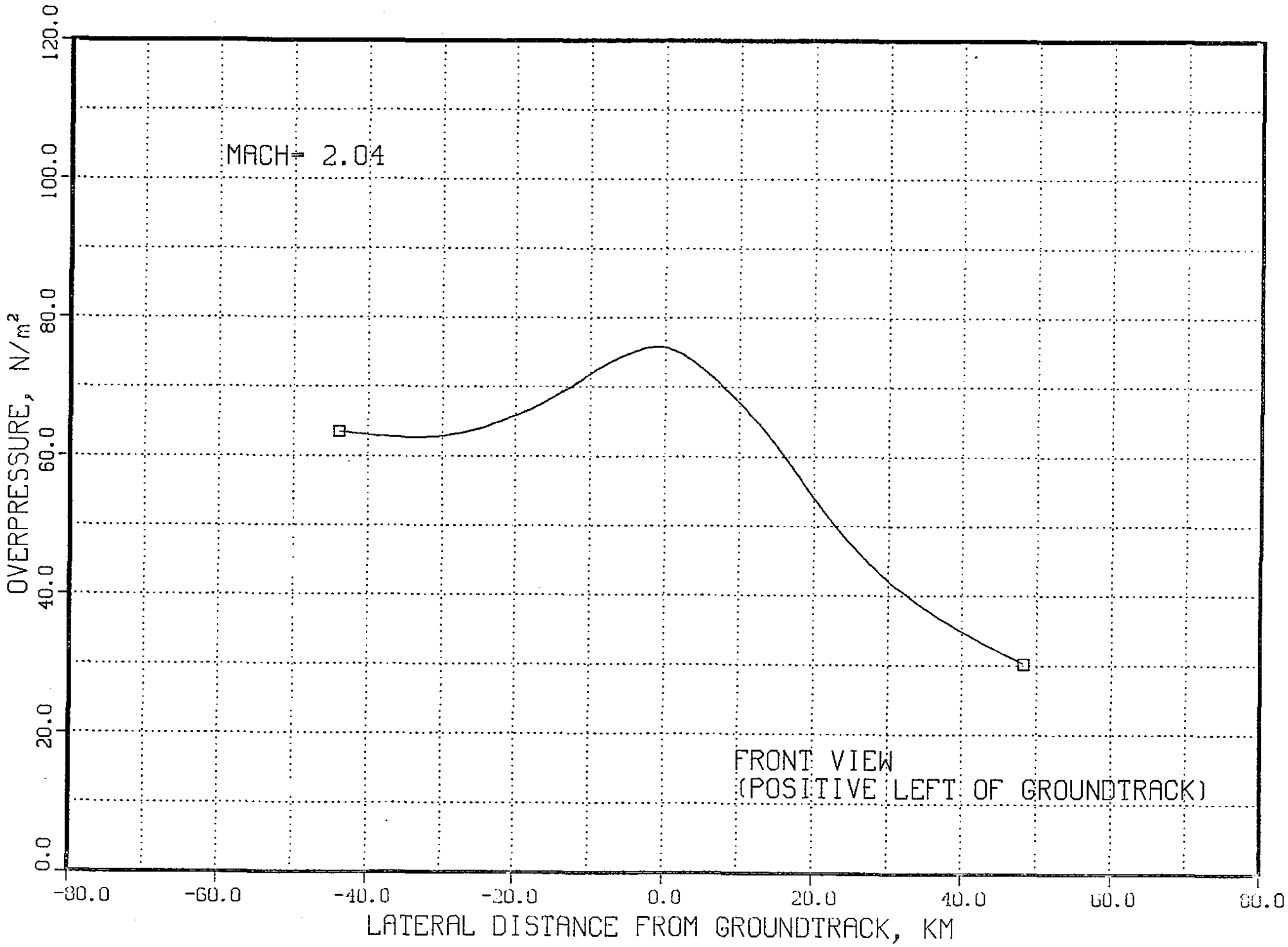

Figure 13.- Lateral distribution of overpressure level (Mach number = 2.04).

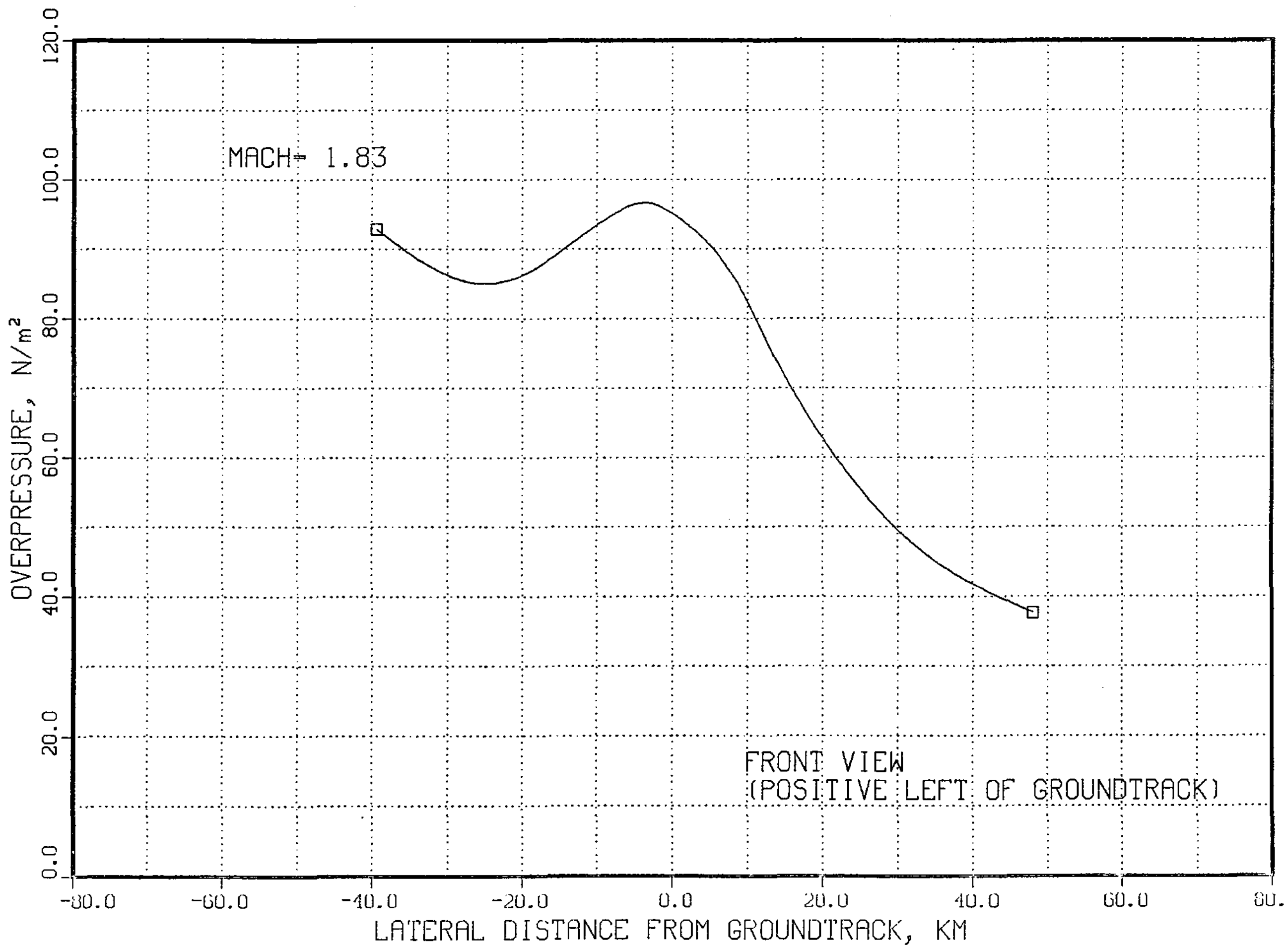

Figure 14.- Lateral distribution of overpressure level (Mach number = 1.83).

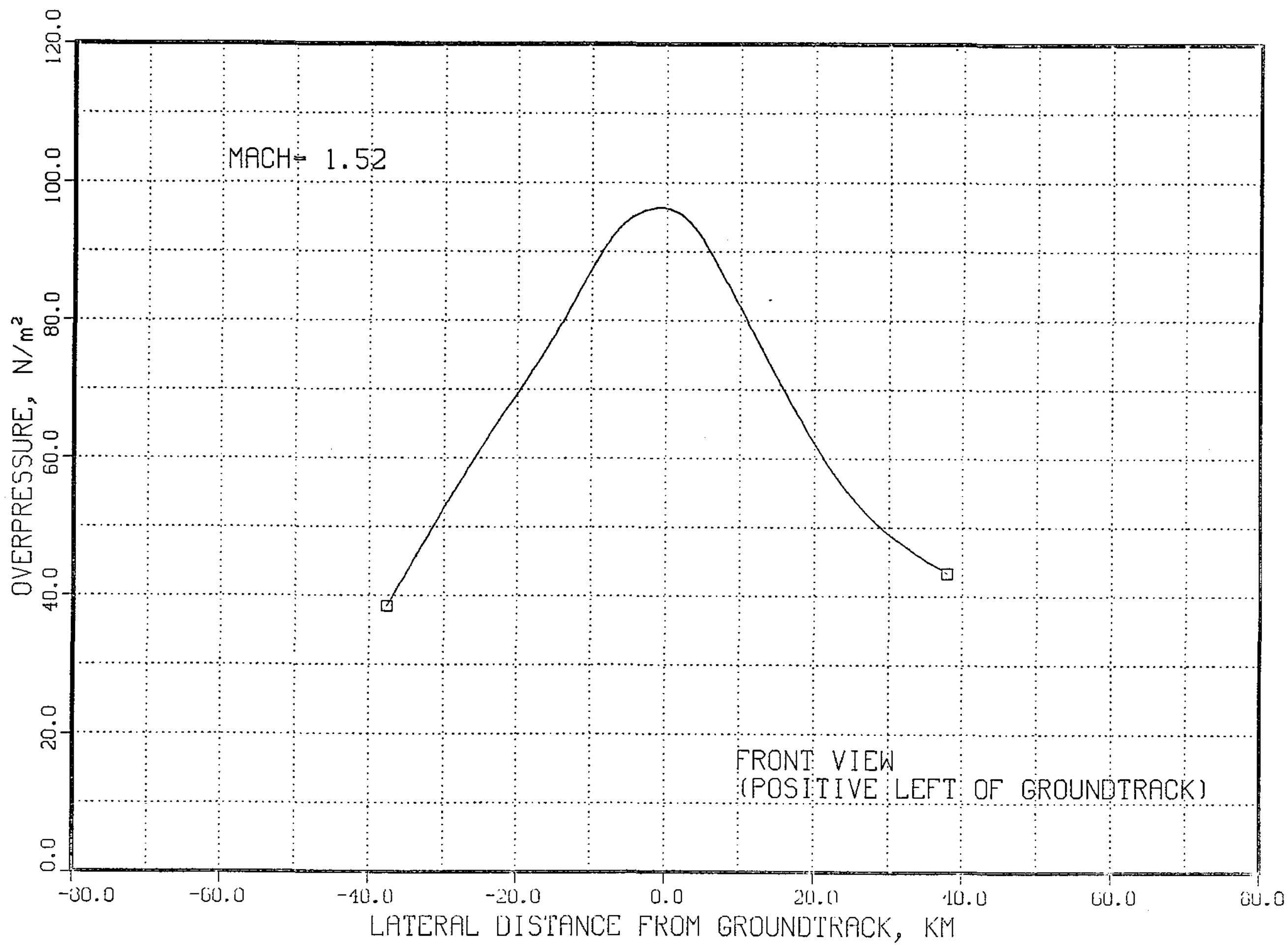

Figure 15.- Lateral distribution of overpressure level (Mach number = 1.52).

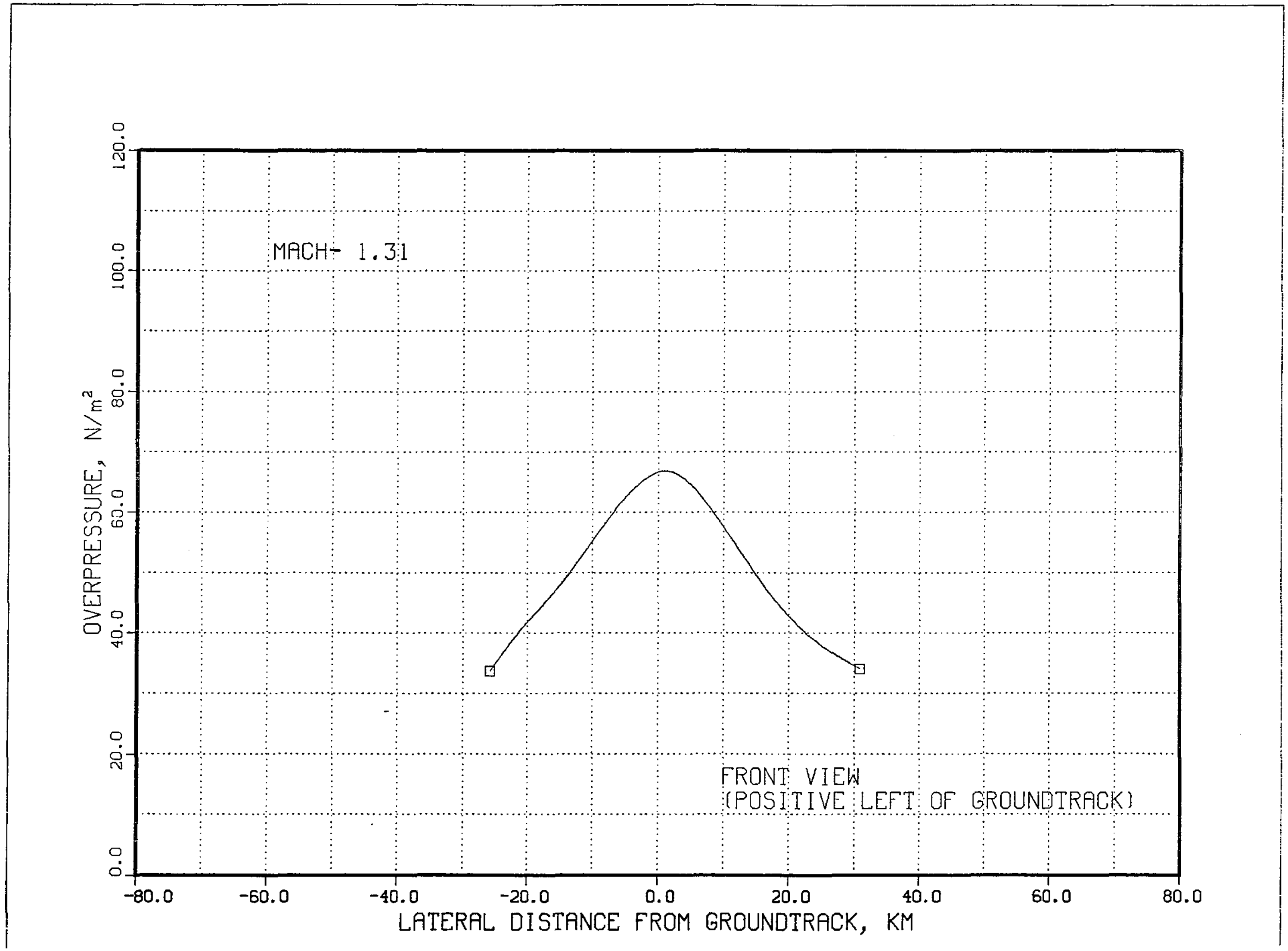

Figure 16.- Lateral distribution of overpressure level (Mach number = 1.31).

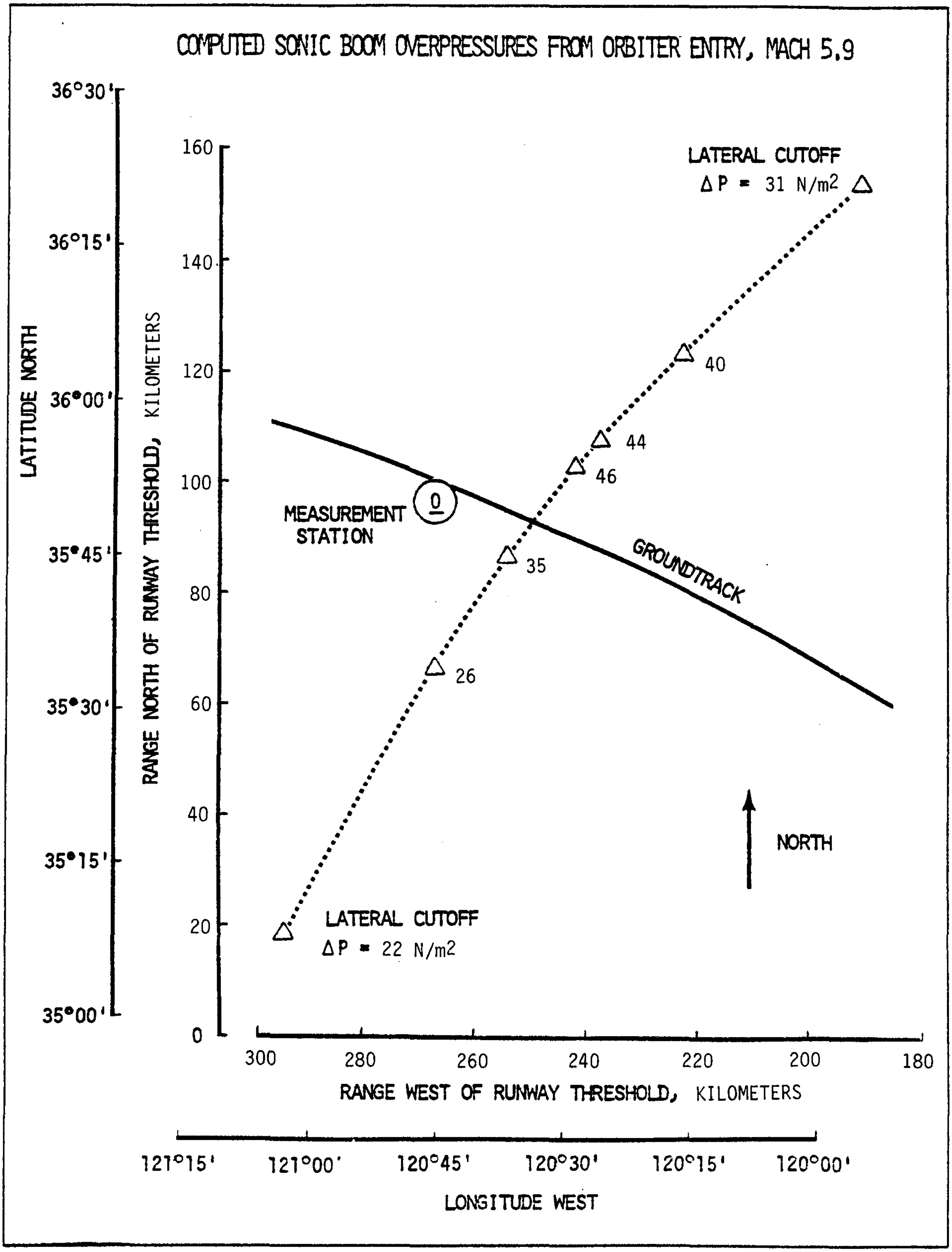

Figure 17.- Predicted groundlevel overpressure contour (Mach number = 5.89).

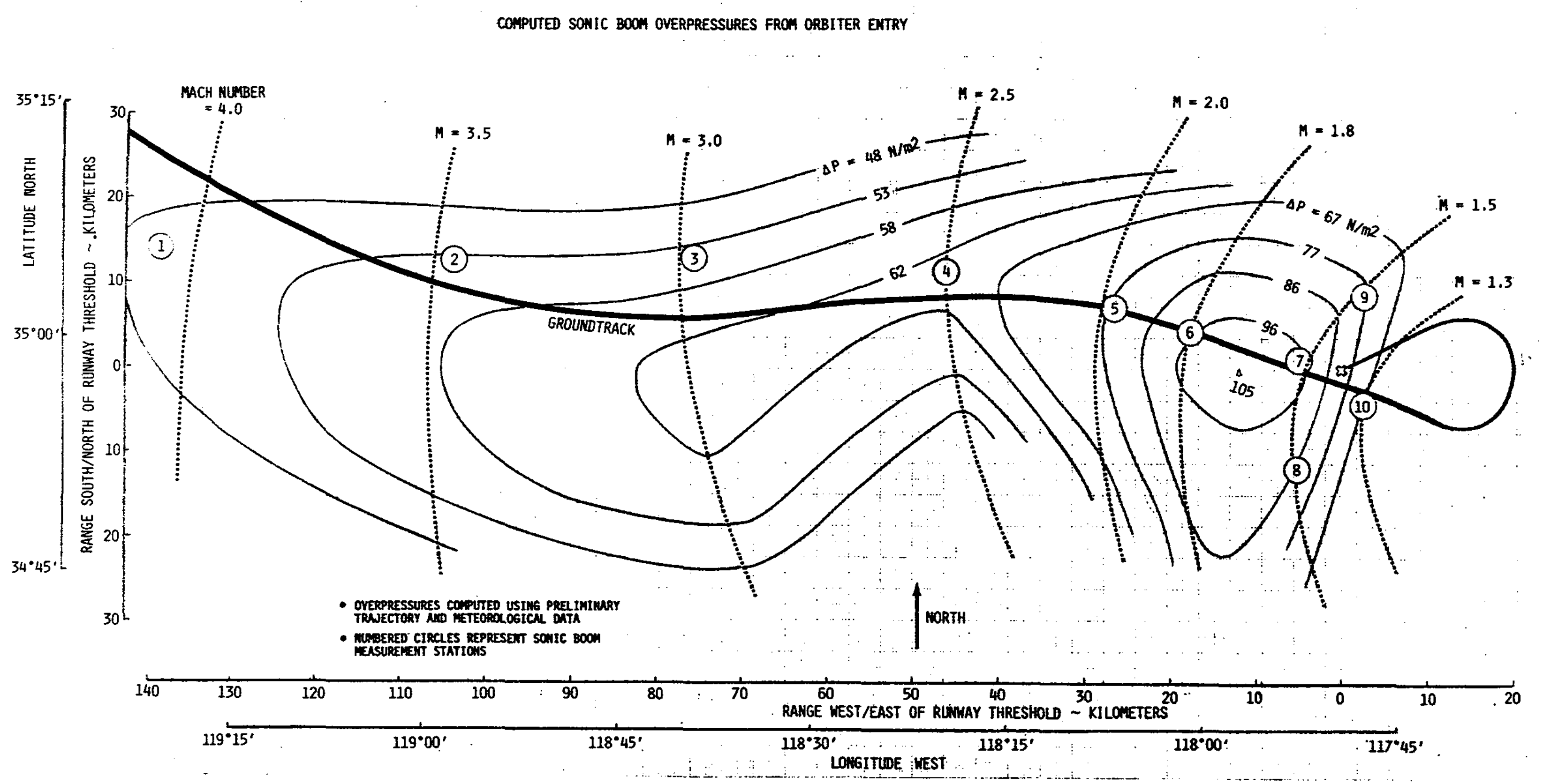

Figure 18.- Predicted groundlevel overpressure contours (Mach number = 4.02 to 1.3).

1. Report No. NASA TM-58242	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle Preliminary Sonic Boom Correlation of Predicted and Measured Levels for STS-1 Entry		5. Report Date February 1982
		6. Performing Organization Code
7. Author(s) Frank Garcia, Jr. and Karen M. Morrison, JSC; Jess H. Jones, MSFC; Herbert R. Henderson, LaRC		8. Performing Organization Report No. S-511
9. Performing Organization Name and Address Lyndon B. Johnson Space Center, Houston, TX 77058		10. Work Unit No. 953-36-00-00-72
		11. Contract or Grant No.
12. Sponsoring Agency Name and Address National Aeronautics and Space Administration, Washington, D.C. 20546		13. Type of Report and Period Covered Technical Memorandum
		14. Sponsoring Agency Code

15. Supplementary Notes

A preliminary analysis correlating peaks from sonic boom pressure signatures recorded

16. Abstract

A preliminary analysis correlating peaks from sonic boom pressure signatures recorded during the descent trajectory of the Orbiter Columbia, which landed in the dry lake bed at Edwards Air Force Base (EAFB), California, with measured wind tunnel signatures extrapolated from flight altitudes to the ground has been made for Mach numbers ranging from 1.3 to 6. The flight pressure signatures were recorded by microphones positioned at ground level near the groundtrack, whereas the wind tunnel signatures were measured during a test of a 0.0041-scale model Orbiter. The agreement between overpressure estimates based on wind tunnel data using preliminary flight trajectory data and oscillograph traces from ground measurements appears reasonable at this time for the range of Mach numbers considered. More detailed studies using final flight trajectory data and digitized ground measured data will be performed.

17. Key Words (Suggested by Author(s)) Measured and Predicted; Space Shuttle Orbiter Columbia; Orbiter sonic booms; STS-1 Entry	18. Distribution Statement Limited distribution - preliminary data; STAR Category: 71

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price*
Unclassified	Unclassified	38	

*For sale by the National Technical Information Service, Springfield, Virginia 22161